CCAMLR Science, Vol. 9 (2002): 133–143

SHORT NOTE

OTOLITH AND BODY SIZE RELATIONSHIPS IN BIGEYE GRENADIER (*MACROURUS HOLOTRACHYS*) IN CCAMLR SUBAREA 48.3

S. Morley and M. Belchier✉
British Antarctic Survey
High Cross, Madingley Road
Cambridge CB3 0ET, United Kingdom
Email – markb@bas.ac.uk

Abstract

A large sample of otoliths from bigeye grenadier (*Macrourus holotrachys*) caught as by-catch in the Patagonian toothfish (*Dissostichus eleginoides*) fishery in Subarea 48.3 was measured and weighed, and the usefulness of otoliths as predictors of fish size was determined. Otolith mass provides good estimates of fish length, whereas otolith length and width measurements provide less accurate estimates of fish length. Seasonal variations in fish mass with reproductive condition need to be considered if predictions of fish mass from otolith mass are undertaken. Otolith size/fish size models should be derived for each fish population under investigation. The length of fish chosen in such studies should be representative of the size range consumed by predators.

Résumé

Un échantillon important d'otolithes de grenadiers gros-yeux (*Macrourus holotrachys*) prélevé dans la capture accessoire de la pêcherie de légine australe (*Dissostichus eleginoides*) de la sous-zone 48.3 a été mesuré et pesé pour déterminer si les otolithes pouvaient être considérés comme des indicateurs de la taille des poissons. Le poids des otolithes donne une bonne estimation de la longueur des poissons, alors que la longueur et la largeur des otolithes n'en donnent pas d'estimations aussi précises. Les variations saisonnières du poids des poissons en fonction de la condition de reproduction doivent être prises en compte si l'on entreprend de déterminer le poids des poissons à partir de celui des otolithes. Il conviendrait de dériver des modèles de taille des otolithes/taille des poissons pour chaque population de poissons à l'étude. La longueur des poissons retenus dans de telles études devrait être représentative de l'intervalle des tailles consommé par les prédateurs.

Резюме

Было измерено и взвешено большое количество отолитов южноатлантического макруруса (*Macrourus holotrachys*), выловленного как прилов при промысле патагонского клыкача (*Dissostichus eleginoides*) в Подрайоне 48.3, и оценена полезность отолитов в качестве предикторов размера рыбы. Масса отолита позволяет хорошо оценить длину рыбы, в то время, как длина и ширина отолита дают менее точную оценку длины рыбы. Если масса отолита используется для оценки массы рыбы, то необходимо учитывать также сезонную изменчивость массы рыбы в зависимости от репродуктивного состояния. Модели размера отолитов/размера рыбы должны составляться для каждой изучаемой популяции рыб. Длина рыбы, выбираемой для таких исследований, должна отражать диапазон размеров рыбы, потребляемой хищниками.

Resumen

Se midió y pesó una gran cantidad de muestras de otolitos del granadero ojisapo (*Macrourus holotrachys*) extraído como captura secundaria en la pesca del bacalao de profundidad (*Dissostichus eleginoides*) en la Subárea 48.3, y se determinó la utilidad de los otolitos como variable predictora de la talla de los peces. La masa del otolito ofrece buenas estimaciones de la talla de los peces, mientras que las mediciones del ancho y del largo del otolito entregan estimaciones menos precisas de la talla de los peces. Al efectuar predicciones del peso del pez a partir de la masa del otolito, se deben considerar las variaciones estacionales en el peso del pez de acuerdo con el estado reproductor. Los modelos para predecir la talla del pez a partir del tamaño/peso del otolito deben ser elaborados para cada población de peces objeto de estudio. La talla de los peces escogidos en tales estudios debiera ser representativa del intervalo de tallas de los peces consumidos por los depredadores.

Keywords: otolith size, fish length, by-catch, *Macrourus holotrachys,* Subarea 48.3, CCAMLR

INTRODUCTION

Fish of the family Macrouridae (rattails and grenadiers) are regularly taken as by-catch in the longline fisheries for toothfish (*Dissostichus* spp.) in the Southern Ocean. In certain areas, such as the Ross Sea and around the Kerguelen Islands, macrourids may comprise as much as 17–23% of the total catch by weight in these fisheries (van Wijk et al., 2000). In other fisheries, such as the Patagonian toothfish (*Dissostichus eleginoides*) fishery at South Georgia and Shag Rocks (Subarea 48.3), reported macrourid by-catch is less, between 1–2% of the total catch weight. However, even in these regions, the total catch of macrourids may amount to between 10 and 25 tonnes each year (CCAMLR, 2000).

There are currently very few data available on the population abundance of macrourids or of their interactions in the Southern Ocean ecosystem. In the waters around South Georgia and Macquarie Island macrourids of the genus *Macrourus* occur in the diet of *D. eleginoides* (Garcia de la Rosa et al., 1997; Goldsworthy et al., 2001), and discarded by-catch fish are known to be taken by black-browed and grey-headed albatrosses (Xavier et al., 2002). It is likely that within the Southern Ocean ecosystem, as elsewhere, macrourids are important predators of benthic and mid-water fish and invertebrates (Merrett and Haedrich, 1997).

The analysis of otoliths retrieved from diet samples of higher predators can be used to provide information on the type, size, mass and energetic content of their fish prey (Reid, 1995; Bowen, 2000). However, useful information can only be obtained from the otoliths if the relationship between otolith size and fish size is established (Everson et al., 1999). Existing information on otolith size/fish size relationships for Southern Ocean macrourids has been obtained from only a small sample of *Macrourus holotrachys* otoliths (n = 15) from fish caught around Heard and Macquarie Islands (Williams and McEldowney, 1990). Here we present the results obtained from a large sample of otoliths of *M. holotrachys* taken as by-catch in the commercial longline fishery for toothfish around South Georgia.

MATERIALS AND METHODS

In total 230 macrourids were obtained from CCAMLR observers on board commercial toothfish longline vessels fishing within Subarea 48.3 between June and August 2001. Specimens were frozen and then thawed prior to examination at the British Antarctic Survey (BAS) laboratory at King Edward Point, South Georgia. Fish were identified using the methods of Iwamoto (1990), Miller (1993) and Fischer and Hureau (1985). Fish were identified using a number of characteristics including the extent of squamation on the underside of the head, lunate areas behind the snout, and the number of pelvic fin rays as described by Trunov and Konstantinov (1986). The majority of these (227) were identified as belonging to one species, *M. holotrachys.* The following data were collected for each fish: total length L_t (cm), anal length L_a (cm) and total mass W_t (kg). Anal length is the measure of macrourid length routinely taken because damage to the long fragile tail can lead to inaccuracies in total length estimation. Left and right sagittal otoliths were removed and examined under a light microscope. If they appeared to be undamaged, the otolith length L_o (mm) and otolith width Wd_o (mm) were measured to the nearest 0.001 mm using electronic calipers according to the methods of Williams and McEldowney (1990). The total otolith mass, W_o (g), was measured to the nearest 0.01 g using a standard analytical balance.

The relationships between otolith length L_o (mm), otolith width Wd_o (mm) and otolith mass W_o (g) and fish total length L_t (cm), anal length L_a (cm) and total mass W_t were investigated. Fish and otolith weights were log-transformed to linearise data for the calculation of 95% confidence limits of regressions and associated predictions. Data were subsequently back-transformed to natural units. The relationships between fish total length L_t (cm), anal length L_a (cm) and total mass W_t were also investigated.

RESULTS

The majority of *M. holotrachys* examined were female (219 of 227) and ranged in size from 47 to 80 cm L_t. A paired *t*-test comparison of the dimensions of the left and right otoliths revealed no significant differences in otolith length (T = 0.76, p = 0.45, n = 213), otolith width (T = 0.34, p = 0.74, n = 219) or otolith mass (T = 0.24, p = 0.81, n = 212), enabling measurements of either otolith to be used in subsequent analyses. Regressions of otolith length against fish length (total and anal) and fish mass indicate simple relationships between variables with otolith length increasing with increasing body size. The data are reasonably well fitted with simple linear regressions. Similar results are obtained from scatter plots of otolith width against fish length and mass. The results of these regression analyses are given in Table 1. Significant relationships exist between otolith linear measurements and fish size, however r^2 values are low and there is much scatter in the data. The predictive capabilities of all of the models are similar.

Scatter plots of otolith weight against fish length and weight are shown with fitted curves in Figure 1. Significant relationships exist between fish size and otolith mass (W_o (g)), $p < 0.001$ in all cases. The regression equations describing the relationships are:

total length L_t (cm) = 92.09 $(W_o)^{0.295}$ (r^2 = 0.61)
anal length L_a (cm) = 38.093 $(W_o)^{0.367}$ (r^2 = 0.60)
total weight W_t (kg) = 5.68 $(W_o)^{1.017}$ (r^2 = 0.62).

Higher r^2 values compared to those obtained when using otolith linear dimensions as variables suggest that otolith mass can provide a more useful predictor of fish size than otolith length or width measurements. The predictive capability of the fitted models is compared in Table 2. Confidence Intervals (CI) for predictions based on otolith mass range from ±3 cm for the smallest fish analysed (17 cm anal length) rising to ±5 cm for the largest. CIs for predictions based on otolith length range from ±4 cm for the smallest fish to ±6 cm for the largest. The confidence intervals of predictions of fish size based on otolith length are greater and hence less useful than those obtained from the fish length/otolith mass model.

A comparison of the results of the current study with published data for *M. holotrachys* is shown in Figure 2. There are substantial differences in the slope and intercepts of the regression equations, which in turn give rise to differences in the fish size predictions for each model (Table 3).

Scatter plots of fish total length against fish anal length and fish total length against total mass are shown in Figure 3. A linear regression best describes the relationship between fish total length and anal length whilst fish weight is approximately the cube of total length.

DISCUSSION

The study was undertaken to evaluate whether data obtained from studies on predators can be used to obtain information on their macrourid prey. The aim of such studies, which examine otoliths from sources such as bird and fish stomachs, is to estimate the biomass of the fish consumed. The results from this study indicate that otolith size (i.e. length or width) or mass, can be used to predict the size of the fish from which it was taken. However, otolith weight is a far better predictor of fish size than either otolith length or width. When otolith mass is used as a predictor, the regression explained over 60% of the variation of the data, an improvement on the 30% obtained when using otolith size. A similar result was obtained in mackerel icefish (*Champsocephalus gunnari*) by Everson et al. (1999).

Despite their widespread use, problems may exist when otolith dimensions are employed to reconstruct the size structure of the fish prey items found in the diets of marine predators. One difficulty is that otoliths may erode during digestion and that the degree of erosion is species-specific (Bowen, 2000). Degradation due to digestion may result in biases when otoliths are used to identify diet composition in higher predators. 'Compensation Factors' derived from in-vitro feeding experiments are often applied in dietary studies to compensate for otolith erosion, enabling fish length and mass to be calculated (Reid, 1995). North et al. (1983) suggested that *C. gunnari* otoliths from seal faeces lost 10–20% of their length during digestion, whereas those from

Table 1: Results of the linear regression analysis ($y = bx + A$) of fish body size (L_t, L_a and W_t) against otolith length and otolith width.

	Otolith Length (L_o)			
	A	*B*	R^2	*P*
Length (L_t cm)	27.81	2.40	0.28	<0.001
Anal length (L_a cm)	5.87	1.22	0.33	<0.001
Weight (W_t kg)	-1.55	0.21	0.33	<0.001
	Otolith Width (Wd_o)			
	A	*B*	R^2	*P*
Length (L_t cm)	20.01	5.96	0.36	<0.001
Anal length (L_a cm)	5.19	2.57	0.35	<0.001
Weight (W_t kg)	-1.47	0.42	0.31	<0.001

Table 2: Comparison of fish anal length (L_a cm) predicted from (a) otolith mass and (b) otolith length. Upper and lower 95% confidence limits (CL) are given along with the confidence interval (CI ($CL^{(upper)}$ - $CL^{(lower)}$)).

(a)

Otolith Mass (g)	Predicted Value (cm)	Lower CL (cm)	Upper CL (cm)	CI (cm)
0.1	16.4	13.8	19.4	5.6
0.2	21.1	17.9	24.9	7.0
0.3	24.5	20.8	28.9	8.1
0.4	27.2	23.1	32.1	9.0
0.5	29.5	25.0	34.9	9.8
0.6	31.6	26.7	37.3	10.6

(b)

Otolith Length (mm)	Predicted Value (cm)	Lower CL (cm)	Upper CL (cm)	CI (cm)
10.0	17.6	14.1	21.9	7.8
12.0	20.2	16.3	25.1	8.7
14.0	22.8	18.4	28.2	9.7
16.0	25.3	20.4	31.2	10.8
18.0	27.7	22.3	34.3	11.9
20.0	30.0	24.2	37.3	13.1

Table 3: Comparison of fish total length predicted from otolith length, from the equations of this paper and Williams and McEldowney (1990).

Otolith Length (mm)	Estimated Fish Length (cm)	
	This paper	Williams and McEldowney (1990)
10	51.8	38.1
12	56.6	46.2
14	61.4	54.2
16	66.2	62.2
18	71.0	70.3
20	75.8	78.4

nototheniids had lost 15–25%. There is currently little information available on the digestion rates of macrourid otoliths in predator stomachs. However, the large size and robust structure of *M. holotrachys* otoliths compared to the otoliths of other Southern Ocean fish species suggest that they are much less likely to be eroded during digestion. The potential biases associated with partially eroded otoliths must be borne in mind when reconstructing the fish component of the diet of predators.

COMPARISON WITH OTHER STUDIES

The discrepancies observed between the otolith length/fish size relationships described in the current study and that produced by Williams and McEldowney (1990) are likely to have a number of causes. Williams and McEldowney's (1990) data were obtained from a small sample (n = 15) of smaller fishes (16.3–54.1 cm SL) from Heard and Macquarie Islands compared to the large sample (n = 227) of larger specimens (47–80 cm SL) measured in this study. We would advocate the use of predictions of fish body size from otoliths that have been derived from the fish populations on which the predators have been feeding. Samples cover the widest possible size range to encompass fish of a size representative of those consumed by the predators.

Otolith mass can be used to provide predictions of fish length or fish mass. However, we would not recommend estimating fish mass directly from otolith mass measurements as this is likely to vary with spawning condition. Only otoliths from females were examined in the current study and further investigations on males are required. Previous studies on *C. gunnari* otoliths have, however, found there to be no difference between the size of otoliths in males and females.

Strong relationships between otolith size and fish size have been observed for many species of macrourids found in other parts of the world, including studies on Mediterranean species (Massuti et al., 1995) and those found in South African waters (Smale et al., 1995). Otolith morphology is highly species-specific, therefore direct comparisons with these results were not undertaken. It is clear, however, that when undertaking such studies measurements should be standardised.

CONCLUSIONS

(i) Otolith size can be used to predict fish size in *M. holotrachys.*

(ii) Otolith mass provides a better predictor of fish length than otolith size.

(iii) Seasonal variations in fish mass with condition need to be considered if predictions of fish weight from otolith mass are undertaken.

(iv) Otolith size/fish size models should be derived for each fish population under investigation.

ACKNOWLEDGEMENTS

The authors gratefully acknowledge the assistance of J. Dickson and T. Mulvey at King Edward Point. We would also like to acknowledge the dedication of all of the observers who collected material for us.

REFERENCES

CCAMLR. 2000. *Statistical Bulletin*, Vol. 12 (1989–1999). CCAMLR, Hobart, Australia.

Bowen, W.D. 2000. Reconstruction of pinniped diets: accounting for complete digestion of otoliths and cephalopod beaks. *Can. J. Fish. Aquat. Sci*., 57: 898–905.

Everson, I., B. Bendall and A. Murray. 1999. Otolith and body size relationships in the mackerel icefish (*Champsocephalus gunnari*). *CCAMLR Science, 6*: 117–123.

Fischer, W. and J.-C. Hureau (Eds). 1985. *FAO Species Identification Sheets for Fishery Purposes. Southern Ocean (CCAMLR Convention Area Fishing Areas 48, 58 and 88)*, Vol. II: 233–470. Prepared and published with the support of the Commission for the Conservation of Antarctic Marine Living Resources. FAO, Rome.

García de la Rosa, S.B., F. Sánchez and D. Figuero. 1997. Comparative feeding ecology of Patagonian toothfish (*Dissostichus eleginoides*) in the southwestern Atlantic. *CCAMLR Science*, 4: 105–124.

Goldsworthy, S.D., X. He, G.N. Tuck, M. Lewis and R.W. Williams. 2001. Trophic interactions between the Patagonian toothfish, its fishery, and seals and seabirds around Macquarie Island. *Mar. Ecol. Prog. Ser*., 218: 283–302.

Iwamoto, T. 1990. Macrouridae (Grenadiers). In: Gon, O. and P.C. Heemstra (Eds). *Fishes of the Southern Ocean.* J.L.B. Smith Institute of Ichthyology, Grahamstown: 462 pp.

Massuti, E., B. Morales-Nin and C. Stefanescu. 1995. Distribution and biology of five grenadier fish (Pisces: Macrouridae) from the upper and middle slope of the northwestern Mediterranean. *Deep-Sea Res*., I, 42 (3): 307–330.

Merrett, N.R. and R.L. Haedrich. 1997. *Deep-sea Demersal Fish and Fisheries*. Chapman and Hall, London: 282 pp.

Miller, R.G. 1993. *History and Atlas of the Fishes of the Antarctic Ocean*. Foresta Institute for Ocean and Mountain Studies, Carson City, Nevada: 792 pp.

North, A.W., J.P. Croxall and D.W. Doidge. 1983. Fish prey of the Antarctic fur seal *Arctocephalus gazella* at South Georgia. *British Antarctic Survey Bulletin*, 61: 27–38.

Reid, K. 1995. Diet of Antarctic fur seals (*Arctocephalus gazella* Peters 1875) during winter at South Georgia. *Ant. Sci.*, 7 (3): 241–249.

Smale, M.J., G. Watson and T. Hecht. 1995. *Otolith Atlas of Southern African Marine Fishes*. Ichthyological Monographs of the J.L.B. Smith Institute of Ichthyology, No. 1xiv: 253 pp.

Trunov, I.A. and V.V. Konstantinov. 1986. On the separation of the species *Macrourus carinatus* (Günther) and *M. holotrachys* Günther (Macrouridae). *Proceedings of the Zoological Institute, Leningrad*, 153: 125–135.

van Wijk, E.M., A.J. Constable, R. Williams and T. Lamb. 2000. Distribution and abundance of *Macrourus carinatus* on BANZARE Bank in the southern Indian Ocean. *CCAMLR Science*, 7: 171–178.

Williams, R. and A. McEldowney. 1990. A guide to the fish otoliths from waters off the Australian Territory, Heard and Macquarie Islands. *ANARE Research Notes*, 75: 1–173.

Xavier, J.C., J.P. Croxall and K. Reid. 2002. Interannual variation in the diets of two albatross species breeding at South Georgia: implications of breeding performance. *Ibis*: in press.

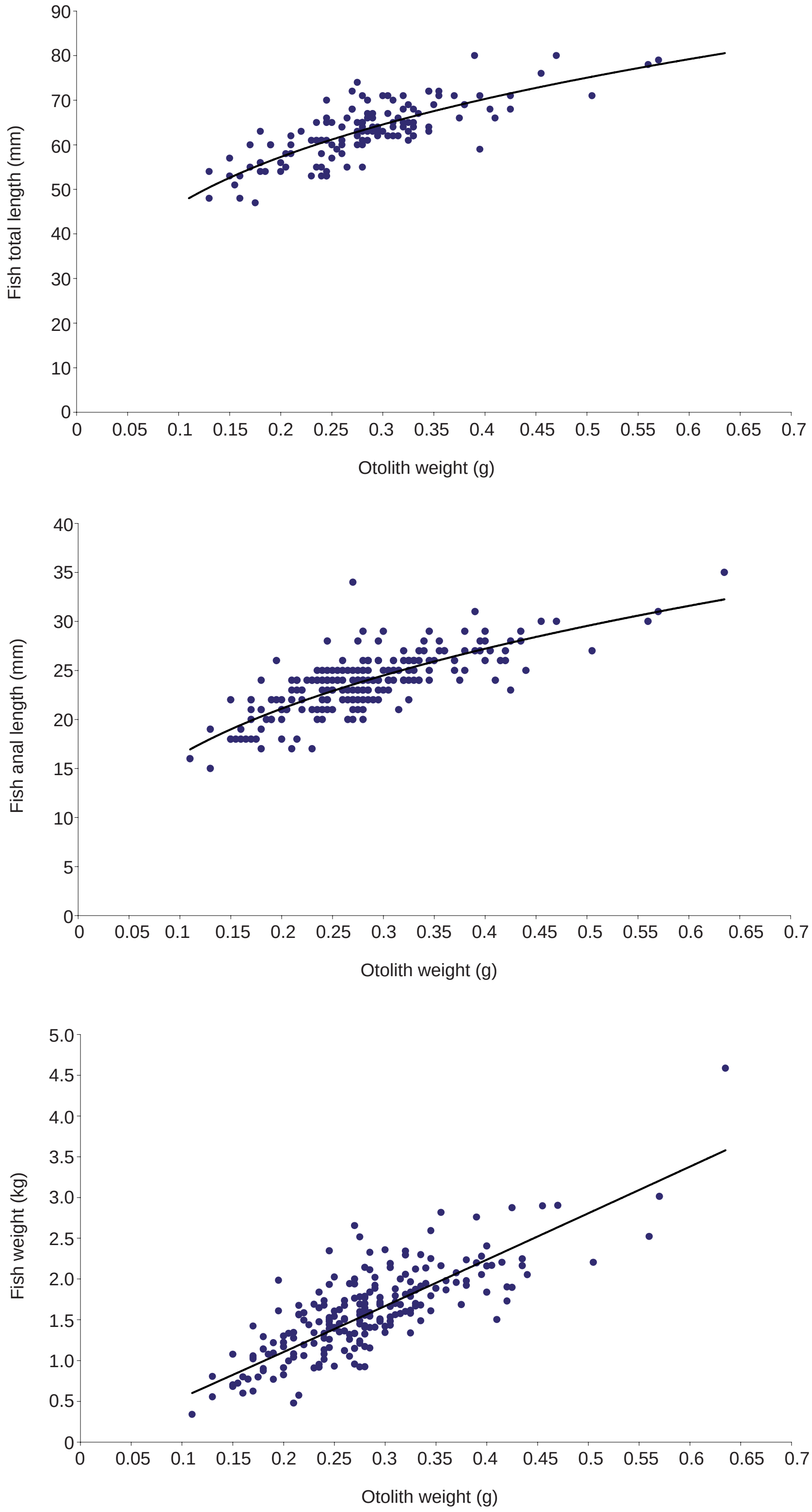


Figure 1: Scatter plots of total length L_t (cm), anal length L_a (cm) and total weight W_t (kg) against otolith mass (W_o (g)). The equations of the fitted lines are given in the text.

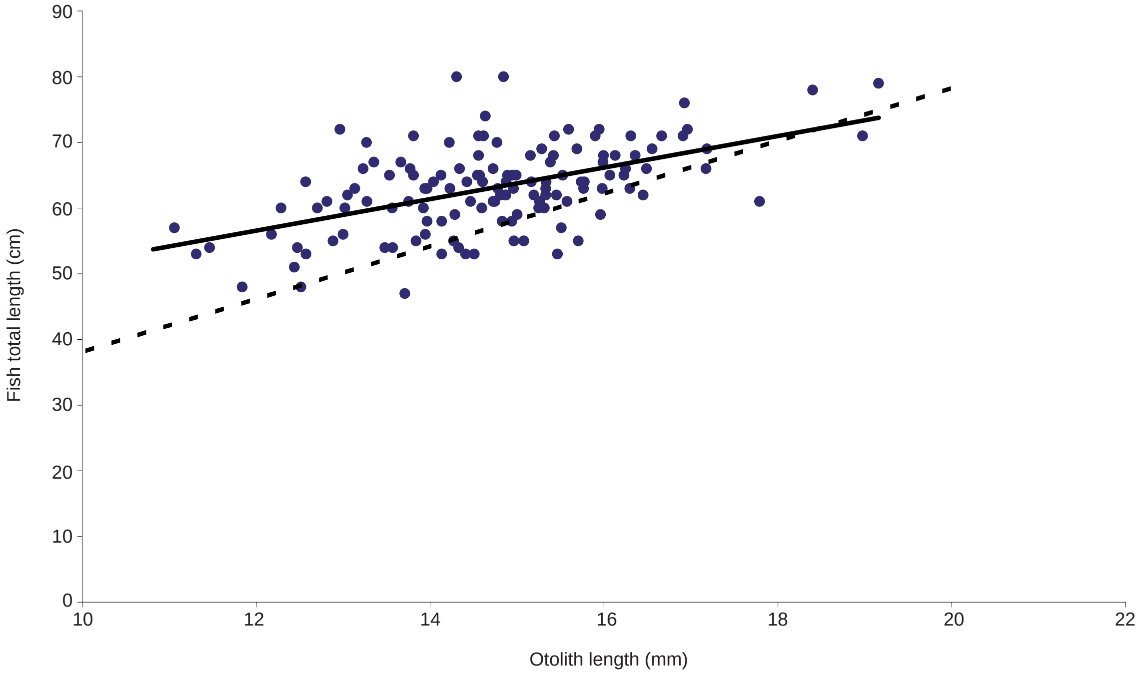
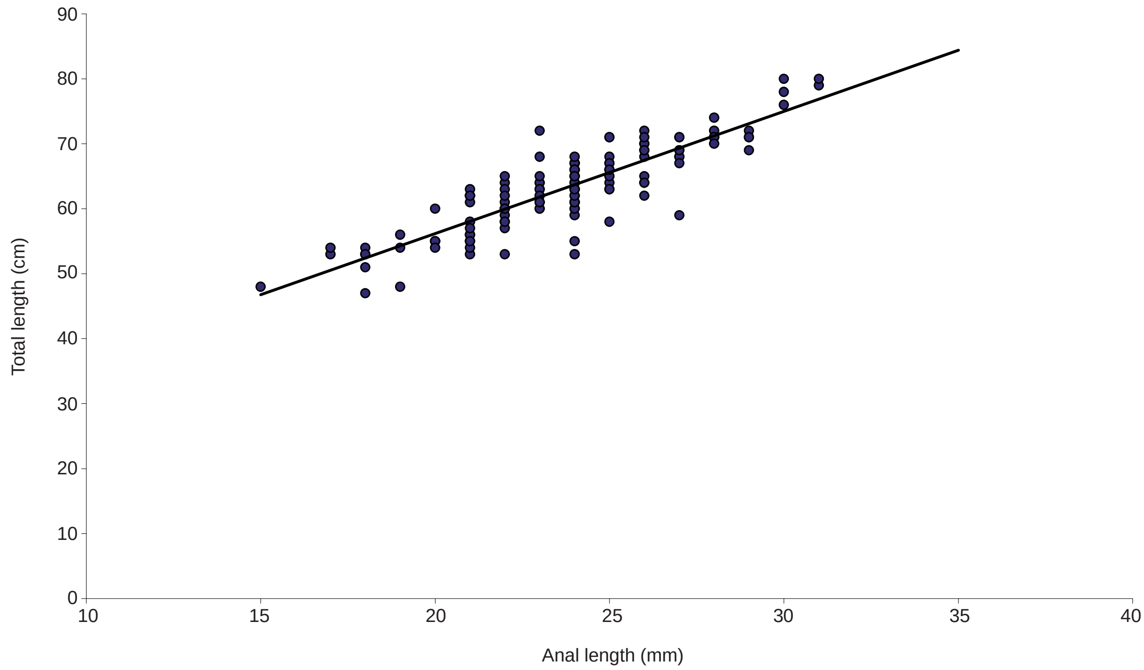


Figure 2: Scatter plot of total length L_t (cm) against otolith length L_o (mm). The solid line is the linear regression line for the data. The dashed line represents the linear relationship between fish length and otolith length obtained by Williams and McEldowney (1990) for *Macrourus holotrachys* otoliths from Heard and Macquarie Islands.



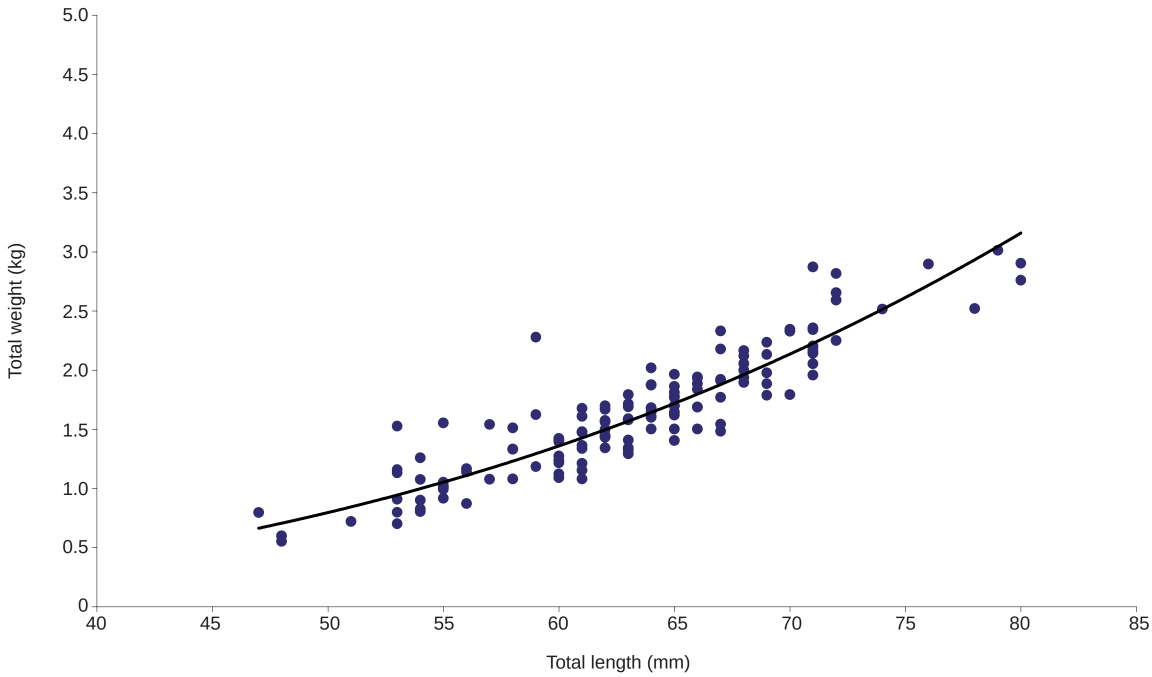


Figure 3: Scatter plots of fish total length L_t (cm) against anal length L_a (cm) (top) and fish total weight W_t (kg) against fish total length L_t (cm) (bottom). The equations of the fitted lines are $L_{(t)} = 1.8834\ L_{(a)} + 18.501$ ($r_2 = 0.7536$, Top) and $W_{(t)} = 8 \times 10^{-6}\ L_{(t)}^{2.93}$ ($r_2 = 0.8221$, bottom).

Liste des tableaux

Liste des figures

Список таблиц

Список рисунков

Lista de las tablas

Tabla 2: Comparación de la longitud preanal (L_a cm) derivada de (a) el peso del otolito y (b) el largo del otolito. Se muestra el límite superior e inferior del intervalo de confianza del 95% (CL) junto con el intervalo de confianza (CI ($CL^{(superior)}$ - $CL^{(inferior)}$)).

Tabla 3: Comparación de la longitud total del pez derivada del largo del otolito a partir de las ecuaciones presentadas en este trabajo y en Williams y McEldowney (1990).

Lista de las figuras

Figura 1: Diagramas de dispersión de la longitud total L_t (cm), longitud preanal L_a (cm) y peso total W_t (kg) en función de la masa del otolito (W_o (g)). Las ecuaciones de las líneas ajustadas figuran en el texto.

Figura 2: Diagrama de dispersión de la longitud total L_t (cm) en función del largo del otolito L_o (mm). La línea continua representa la regresión lineal de los datos. La línea discontinua representa la relación lineal entre la talla del pez y el largo del otolito derivada de Williams y McEldowney (1990) para los otolitos de *Macrourus holotrachys* de las islas Heard y Macquarie.

Figura 3: Diagramas de dispersión de la longitud total de los peces L_t (cm) en función de la longitud preanal L_a (cm) (superior) y el peso total del pez W_t (kg) en función de la longitud total del pez L_t (cm) (inferior). Las ecuaciones de las líneas ajustadas son $L_{(t)}$ = 1,8834 $L_{(a)}$ + 18,501 (r_2 = 0,7536, superior) y $W_{(t)}$ = 8 x 10^{-6} $L_{(t)}^{2,93}$ (r_2 = 0,8221, inferior).